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BOOK REVIEW

History and Philosophy of Science Inside Chemistry: Implications for Chemistry Education

Mansoor Niaz (2016) *Chemistry Education and Contributions from History and Philosophy of Science.* Springer, Dordrecht,

By Kevin C. de Berg

Introduction

This book is a contribution to the Springer series titled, Science: Philosophy, History and Education, with series editor Kostas Kampourakis. What is refreshing about this book by Niaz is the significant weight given to both philosophical and historical discussion as they relate to chemistry education. Those familiar with Niaz's publications since the 1990's will recognize the following key ideas which populate almost every chapter of his book: ''history of chemistry is already inside chemistry''; and ''historical reconstructions of different episodes in science constitute an important means for understanding how science develops and progresses''. Niaz is also known for his work on textbook analysis, and this methodology appears in various chapters. There are eight chapters in the book with the following titles:

1. Introduction
2. Models, Theories, and Laws in Philosophy of science and Science Education
3. Nature of Science in Science Education: An Integrated View
4. Understanding Atomic Models in Chemistry: Why Do Models Change?
5. Understanding Stoichiometry: Do Scientific Laws Help in Learning Science?
6. Understanding Valence Bond and Molecular Orbital Models: Contingency at Work
7. An Overview of Research in Chemistry Education
8. Conclusions: From Empiricism to Historicism to Naturalism and Beyond

Discussion

The introductory chapter immediately sets out to challenge a still prevalent trend in chemistry education where ''most chemistry courses emphasize the traditional empiricist perspective according to which experimental findings unambiguously lead to the formulation of scientific laws and theories'' (p. 1). The challenge is made by showing how central a theoretical framework was in the work of Mendeleev and the Periodic Table, Lewis and the Covalent Bond, and Pauling and Atomic Theory prior to any experimental investigation. Niaz argues that historical and philosophical investigations of such chemistry topics are important ingredients of what has become known as ''Discipline-Based Education Research in Chemistry''. However, due weight can only be given to these ingredients if we are prepared to ''slow down the science lesson'' (p. 7) and address the meaning of such terms as law, theory, hypothesis as they apply to the practice of science.

It is argued that such an approach in teaching enriches chemistry research and ''the struggle to do both well enriches our personal intellectual lives, and enhances our contributions to society''. This quotation is used by Niaz on page 12 of chapter 1 of his book. Hoffmann is addressing the issue of the relationship between teaching and research in the modern university. He identifies three current views on the relationship: one that views research as the main business of the modern university with teaching taking a somewhat subservient role; one that views teaching and research as complementary with each enhancing the other's role; and finally one that views teaching and research as inseparable, as symbiotic to use Hoffmann's terminology. It is this last view that Hoffmann is promoting. Niaz resonates with this view particularly when history and philosophy of chemistry are involved.

The second chapter devotes considerable space to discussing what is meant by models, theories, and laws in science giving particular attention to chemistry. I found this chapter difficult to read at first given its philosophical slant but found a second and third reading beginning to produce some helpful ideas pertinent to chemistry education. Niaz argues that it is more plausible to approach the nature of models, theories, and laws from the perspective of how these terms are used in the practice of science rather than from the perspective of a priori definitions or preconceptions. The difficulty is that scientists themselves may use these terms in ways that do not reflect the historical development of their subject. Niaz quotes the example of Weinberg who conceptualized progress in science in the following terms: ''What drives us onward in the work of science is precisely the sense that there are truths out there to be discovered, truths that once discovered will form a permanent part of human knowledge''. Giere is then quoted challenging this view:

Weinberg should not need reminding that, at the end of the nineteenth century, physicists were as justified as they could possibly be in thinking that classical mechanics was objectively true. That confidence was shattered by the eventual success of relativity theory and quantum mechanics a generation later.

In contrast to Weinberg's objectivist realism program in science, Giere adopts what he calls a perspectival realism which recognizes that scientists are engaging with the real world as we know it when they propose models, theories and laws, but these entities are not the final word or what might be called the ultimate truth. They are very much part of the human enterprise. It is from the perspective of the history, philosophy and sociology of science that Giere draws this conclusion. Niaz draws upon Giere's work to support his view of the incomplete nature of the models chemists use in describing nature.

As mentioned previously, Niaz is committed to historical reconstructions of key chemical concepts when addressing issues in chemistry education and it is in this context that he devotes some space to examining the views of Duschl and Grandy who view the historical approach as somewhat outdated given the recent trends in what they call the naturalized philosophy of science.

Over the last 100 years, Duschl and Grandy see three major movements in philosophy of science: logical positivism, the historical view of theory development, and currently a model -based view of cognitive and social dynamics based on naturalized philosophy of science. Niaz defends his historical view by appealing to the views of philosophers Denis Phillips and Harvey Siegel who claim that a naturalistic stance in philosophy does not necessarily mean an anti-historical stance. But one is still left wondering how to articulate the ideas of naturalized philosophy of science.

Fifty-two pages are devoted to Nature of Science (NOS) in chapter 3. What will strike the reader in this chapter is that almost all of the examples used to explore NOS are taken from physics or physical chemistry. The biological and Earth sciences tend not to feature in such discussions and consequently discussions on NOS are probably the poorer for it.

However, this book is devoted to chemistry education so one can understand the lack of biological or Earth science data, but many of the examples given still come from physics or the physical side of chemistry. The extent to which this biases the discussion is worthy of future research. However, I think Niaz is justified in agreeing with the conclusions of Campanario that there is a science that we do not teach to our students and consequently they are deprived of an adequate vision of the nature of science. The rest of the chapter basically explores this science not commonly taught in science education in general or chemistry education in particular.

Niaz favours an approach to teaching NOS which integrates what is called the Domain-General approach and the Domain-Specific approach. This is best illustrated by showing a subset of Table 3.1 from the text (pp. 44–45).

Domain-General aspects of NOS	Domain-Specific aspects of NOS
Empirical nature of science	Oil drop experiment to determine electronic charge
Objectivity in science	Awarding the Nobel Prize to Millikan
Competition among rival theories	Valence bond and molecular orbital theories
Different interpretations of the same experimental data	Millikan and Ehrenhaft interpretations of oil drop data
Inconsistent nature of scientific theories	Bohr's model of the atom
Role of refutation or falsification	Synthesis of urea by Wöhler
Theory-laden nature of observations	Millikan's presupposition: atomic nature of electricity
Tentative nature of scientific knowledge	Newtonian mechanics to Einstein's theory of relativity
Scientific ideas affected by social and historic milieu	Michelson–Morley experiment
Systematicity	Demarcation of real science from pseudoscience

Each of these aspects is discussed in some detail along with the associated references which allow the reader to explore the topic in further depth. Niaz discusses his own research on aspects of NOS with a group of 12 doctoral students and his findings from chemistry textbook analyses related to the treatment of NOS by the textbook authors. For those familiar with textbook studies, it is not surprising that ''most science curricula and textbooks in most parts of the world emphasize inductivism, falsificationism, and the scientific method'' (p. 80), contrary to what Niaz paints as a more enlightened view of science and its practice. Significant references are also made to other studies in NOS research. On reading chapter 3, the reader will observe a high degree of repetition which may be a little disconcerting at first, but some of the ideas can bear repeating given their obvious absence from much chemistry curricula.

Chapter 4 is devoted to the changing atomic models in chemistry and traces developments from the Greeks to Boyle to Dalton and on to the modern atomic theory exemplified in the work of Thomson, Rutherford, Bohr and Sommerfeld. Criticism of the story of atomic theory published in textbooks appears to be ultimately Niaz's focus: ''Despite some very good presentations of the historical context in some textbooks, most still follow the empiricist epistemology and hence make it difficult for students to understand the changing nature of atomic models'' (p. 121). A wide range of useful philosophical and historical references is provided by Niaz and what I found particularly interesting was the debate between the philosophers of science, Chalmers and Needham, and the science historian, Rocke, about the contribution of Dalton to atomic theory: ‘‘Returning specifically to Dalton, Rocke... has critiqued both Needham and Chalmers for having overemphasized the importance of the laws of definite and multiple proportions and for having ignored the law of equivalent proportions, which is crucial to all theories of chemical atomism’’ (p. 94). This point is crucial for Niaz as he reviews his chapter 4 (p. 121):

... in order to understand the change and transition from Greeks to Dalton to modern atomic theory (starting in 1897), it is essential to understand that the law of equivalent proportions (among other sources) provided the empirical evidence for Dalton’s atomic theory (Rocke 2013). Without recognizing Dalton’s atomism as a theory, it is difficult to conceptualize the changing nature of atomic models. Of course, just like Thomson’s, Rutherford’s, Bohr’s, and Sommerfeld’s models of the atom were revised, changed, and improved, so was Dalton’s atomic model.

The topic of stoichiometry (Chapter 5) is discussed in the context of whether scientific laws, such as the laws of definite and multiple proportions, assist in the teaching and learning of science. According to Niaz:

The crux of the issue is that ... scientific laws, being epistemological constructions, do not describe the behaviour of actual bodies. Newton’s laws, gas laws, Piaget’s epistemic subject—they all describe the behaviour of ideal bodies that are abstractions from the evidence of experience, and the laws are true only when a considerable number of disturbing factors...are eliminated.

Niaz uses this premise to describe a teaching experiment in Grade 10 Venezuelan classrooms where a group of 31 students was classified as the experimental group and another group of 32 students was classified as the control group. The experimental group was taught using what Niaz describes as a dialectic constructivist strategy where students are presented with questions of a stoichiometric nature and guided through discussion, argument, and historical cases without specifying the laws of stoichiometry. The control group was presented with the same questions but was taught in the traditional sense where the students are firstly introduced to the laws of stoichiometry and are then asked to apply these laws to solving the questions.

The three conceptual questions presented to the students related to the non-stoichiometric production of iron(II) oxide; the production of two oxides of copper, Cu2O and CuO; and a series of hydrocarbons such as ethyne and ethylene, butane and heptane, and ethyne and pentane. In addition, some questions involving the application of algorithmic procedures were asked. It appears that the experimental group outperformed the control group on all conceptual and algorithmic items. However, one wonders whether the conceptual questions proved rather difficult for grade 10 students in both the experimental and control groups, given that only 10 and 0 % respectively of students answered conceptually the item on iron(II) oxide; only 19 and 6 %, respectively, gave conceptual answers to the item on copper oxides; and only 3 and 0 %, respectively, gave conceptual answers to the hydrocarbon item. One would have liked a dialectic constructivist strategy to be more successful than this, but again this probably demonstrates the difficulty science education researchers have had in convincing others of the benefit of constructivist teaching strategies in improving learning outcomes.

Given this dilemma Niaz is nonetheless insightful in directing our attention to this statement by Christie (p. 139): '' ... student responses illustrate to me a problem that I continually find with science students ... an unfamiliarity with thinking critically; an expectation that any question has a 'right' answer, and a mechanical/ algorithmic route to finding that answer''. Niaz sets out to break this mould with the experimental group.

The tentative and contingent character of scientific models is probably best illustrated by the Valence Bond (VB) and Molecular Orbital (MO) models of chemical bonding (Chapter 6). Both these models are used currently in chemistry education and research and were derived subsequent to the development of quantum mechanics; the major architects being Pauling for VB and Mulliken for MO. Niaz sees the major difference between the two models as follows: ''VB emphasized visualization and thus continued the tradition of Lewis, whereas MO treatment was much more mathematical and departed from classical valence theory'' (p. 146). Subsequent developments in software and computer visualization techniques probably render this difference one of less magnitude now. The other difference referred to relates to electron distribution: '' ... in the delocalised molecular orbital picture, several electrons will be found in the same region of space. On the contrary, in valence bond picture electron distribution is localised in individual bonds'' (p. 156). I am wondering here if it would be better to say that in MO theory electron pairs are distributed across multiple nuclei, whereas in VB theory electron pairs belong to just two nuclei. The fact that both models find their place in modern chemistry is consistent with Giere's view that no theory or model can provide a complete and literally correct picture of the world itself (p. 156). A textbook analysis of bonding models has led Niaz to this conclusion (p.155):

Despite evidence to the contrary, many textbooks refer to the failure of VB theory to explain the paramagnetism of the O2 molecule. Actually, early in the development of VB theory, Pauling (1931) had explained that this molecule consisted of two three-electron bonds that explained its paramagnetism.

This is a viewpoint not commonly received in reading a modern textbook. Chapter 7 deals with the following research topics in Chemistry Education based not so much on a cognitive approach as on a history and philosophy of science approach.
1. Kinetic molecular theory of gases
2. Periodic Table of the chemical elements
3. Origin of the covalent bond
4. Oil drop experiment
5. Electrolyte solution chemistry
6. Photoelectric effect
7. Wave-particle duality

What characterizes each of these areas is the role of controversy in chemical epistemology. The reader will observe typical Niaz terminology in these topics: rival research programs; progressive problem shift; progressive sequence of heuristic principles; historical reconstruction; and history of chemistry is already inside chemistry. Although some of these terms have been borrowed from others, they do reflect the orientation and flavour of Niaz's work. There is a rich resource of references for each of these topics. Probably the major purpose of this chapter is to demonstrate that for each topic, experimental data do not constitute evidence for a particular theoretical framework unambiguously without controversy and conflict. Of course, this is what can enrich our teaching and learning of these topics.

In many ways, the final chapter (chapter 8) presents no major material that has not appeared in the previous chapters. It returns to the philosophical discussions of chapter 2 and the trends from empiricism to historicism to naturalism.

Conclusion

I have found this book a valuable resource to read and have made available for more in-depth chemistry topics with which I have to deal. But while I enjoy engaging with philosophical topics I am not a trained philosopher and had particular difficulty trying to articulate in my own mind what is meant by 'naturalism' in philosophy. Whether it refers to how science is practiced in its natural setting by human beings of a certain cognition and social standing or whether it means something entirely different I am not sure. Whatever it means, 'natural' philosophers do not seem to object to incorporating history of science in their modus operandi according to this valuable publication by Mansoor Niaz.